Contribution of InSAR deformation analysis to monitoring Coastal Erosion in the Region of Central Macedonia

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SUMMARY

The combined effects of climate change and human activities are the primary source of soil erosion and its acceleration, which has substantial impact to the anthropogenic environment and financial consequences. The focus of the present work is on the development of processing algorithms and geographic databases for the determination and simulation of coastal erosion and its acceleration within the Region of the Central Macedonia, Greece. Remotely sensed data through the Sentinel constellation, as well as heterogenous in-situ data are employed in order to derive reliable time-series of vertical deformations. In that respect, the Interferometric Synthetic Aperture Radar (InSAR) technique for the detection and monitoring of deformation phenomena has been exploited, while possible correlations to the malformation of the coastal area of Central Macedonia have been analyzed.

A large set of ascending and descending C-band Sentinel – SAR Single Look Complex (SLC) images, covering the period between 2017 and 2020, was employed to an advanced multipass technique that combines unwrapped interferograms with small spatial and temporal baselines to minimize the topographic and atmospheric artifacts. The results obtained by this method showed the existence of subsidence phenomena in urban as well as rural areas. The detected subsidence trend reached absolute values of 2mm/yr over some of the investigated areas. As a final step, the correlation of the obtained results with those obtained from a 50- and 100-year simulation, under the pressure of tidal waves, has been performed. Finally, the generated geospatial infrastructure is outlined, referring to an online platform employing visualization and analysis tools aiming at the creation of an Integrated Observatory of Climate Change in the Region of Central Macedonia.

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1. INTRODUCTION

The Interferometric Synthetic Aperture Radar (InSAR) is a satellite-based remote sensing technique that has been deployed frequently for monitoring subsidence and uplift phenomena with high resolution over short periods of time for the last decades. The technique uses radar images to measure centimeter-level surface displacements over an area of several square kilometers, allowing such phenomena to be monitored sequentially over short periods (Wempen, 2020). These displacement estimations are based on representations of phase differences between SAR acquisitions that cover the same area but were acquired at different times, called interferograms. Processing a number of interferograms can lead to the isolation of the signal component stemming from surface movement (Barra et al., 2017).

InSAR firstly relied on the use of a pair of SAR acquisitions in order to retrieve deformation. Since several algorithmic advances have been achieved in the past years, several new approaches that fully exploit large SAR datasets for the generation of time-series of deformation maps have been generated. Two of the main techniques developed are the Persistent Scatterers (PS) (Ferretti et al., 2001) and the Small Baseline (SB) (Berardino et al., 2002) ones. The first focuses on point-like targets that are basically not affected by decorellation, while the latter relies on selecting SAR data pairs with short temporal (time interval between two acquisitions) and perpendicular distances (between two satellite passes) in order to reduce the noise and detect deformation over distributed scatterers on the ground (Caló et al., 2017).

In this study, we applied the SB approach to detect and measure displacements affecting coastal areas in the Region of Central Macedonia in Northern Greece, which contribute to the analysis of erosion phenomena over the area of interest. Through the generation of displacement time-series maps of deformation rates, the temporal and spatial pattern of land subsidence has been analyzed. Furthermore, the correlation between subsidence phenomena and heterogenous datasets, from traditional ground-based measurements to remote-sensed data from satellites and UAV images, has been investigated. The integration of a variety of datasets that embed local and regional scale information, has contributed to get an insight of the dynamic behavior of the area.

2. STUDY AREA

2.1 The Region of Central Macedonia

The area of interest is located in Central Macedonia, northern Greece (See Figure 1). The region's capital, Thessaloniki, is a metropolitan city with over one million inhabitants. The geomorphology of the region is defined by flat areas to mountainous regions with steep slopes. The maximum elevation (~1200 m) is spotted at Hortiatis mountain while there are coastal areas which reside below the mean sea level. A number of studies have revieled subsidence and uplift phenomena in the area (Mouratidis et al., 2010; Savvaidis et al., 2006). Most of these studies focus on specific regions where natural or anthropogenic activities and environmental changes have taken place, such as the Mygdonia and Anthemountas basin and the Kalochori district (Figure 1).

Figure 1: The Region of Central Macedonia, Greece.

The Mygdonia basin is located in the northern vicinity of Thessaloniki and is considered as one of the most active seismogenic regions in Greece (Papazachos et al., 2001) since it is dominated by almost continuous, but low in magnitude, tectonic activity with a NW-SE to E-W trend and was the epicentral of the major earthquake in 1979 (Mw=7.6) (Raucoules et al., 2008).The Kalochori district is located in the western outskirts of the city of Thessaloniki next to the large deltaic complex that is formed by the rivers Axios, Aliakmonas, Gallikos and Loudias (Raspini et al., 2013). Over the last decades the wider region has become a major industrial area leading to excessive exploitation of the natural aquifers while the Water Supply and Sewage authority of Thessaloniki is performing various drillings there (Loupasakis & Rozos, 2009), (Raspini et al., 2013). Thus, major environmental and morphological changes have been observed in the area including the creation of the Kalochori lagoon (Vareltzidou & Strixner, 2009).

Similar land subsidence and uplift phenomena extend over the broader area presenting low but significant deformation rates. In the majority of the cases, the local authorities remained unnoticed until intense damages took place. Such was the case of Anathemountas basin where infrastructure and buildings' integrity has been damaged irrepably (Bitharis et al., 2017; Raspini et al., 2013).

3. ANALYSIS METHOD

3.1 Input Data and Analysis Method

For the estimation of the deformation rates that occur through time and space, as well as their temporal features, we employed the SB technique and Sentinel 1 SAR images. This technique requires a large number of SAR aqcuisitions characterized by small temporal and spatial baselines. For this purpose, as input data Single Look Complex (SLC) SAR images, orbital information and a high resolution DEM were used. The prossesing algorithm is schemetically depicted in Figure 2.

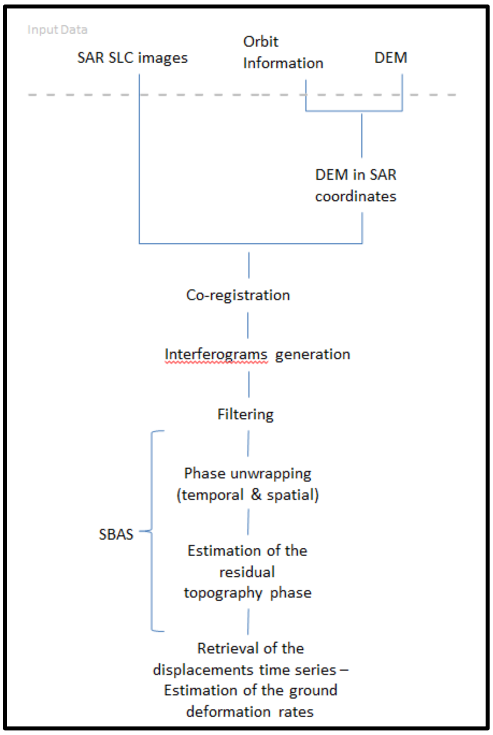

Figure 2 : The applied precessing chain

Three groups of images referred to the same spatial grid, covering the broader area of the Region of Central Macedonia over a period of time between 2017 and 2020. The groups were formed in such way so as to ensure that each image pixel corresponded to the right ground targets (co-registration). For each group, interferometric pairs wre selected in propotion to the spatial and temporal seperation of the SLC images to produce interferogram timeseries.

SB is performed in two stages. First of all, the estimated phase shift is unwrapped through the extended minimum cost flow (EMCF) phase unwrapping (PhU) approach, in order to retrieve its full evolution (Zinno et al., 2015). Then, the unwrapped phase incurred a pixel-based inversion using Singular Value Decomposition (SVD) leading to the estimation of the deformation time series and the deformation rates (Zinno et al., 2015). Using the SB multi-interferogram technique we also managed to minimize the errors caused by atmospheric artifacts. According to Ferretti et al. (2001), the atmospheric component can be computed using space-time filtering steps to the interferometric time-series, due to the fact that atmospheric effects are more related to space than time. The first step includes a low-pass filter in the 2-D spatial domain and it is followed by a high-pass temporal filter. An example of the derived deformations is presented in Figure 3.

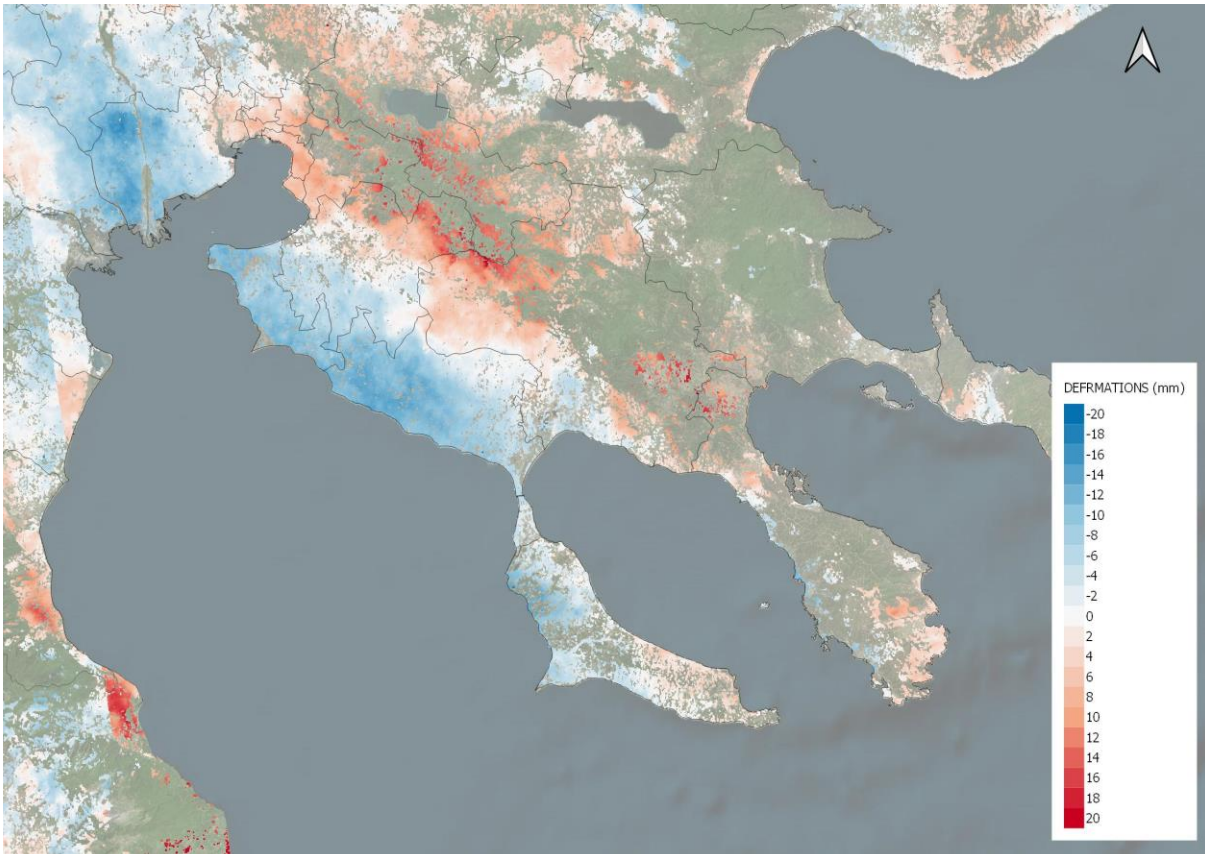

Figure 3: The estimated deformations in the LOS (Sentinel 1 aqcuisitions 26 March 2020 to 04 Apr 2020)

These values refer to the Line of Sight (LOS) of the satellite, therefore their transformation to the vertical direction was required. Since the LOS of Sentinel-1 satellites typically varies between 15 to 45 degrees, in respect to the vertical directionand and due to the fact that SAR observations are more sensitive to the vertical component, for an average incidence angle (27° to 37°, depending on the acquisition), we transformed the LOS mesurements into vertical estimations. The mean vertical deformation rates are presented in Figure 4. The derived velocities are high (more than 2mm/year) in rural areas, which are characterized by low coherance since they are affected by vegetation and topographic decorrelation phenomena, thus the derived results do not describe the real deformation trend of these areas. The noisy areas have a coherence threshold lower than 0.8. (Lu et al., 2018) and therefore they have been excluded. The exclusion of data with low coherence resulted in blank (no data) areas.

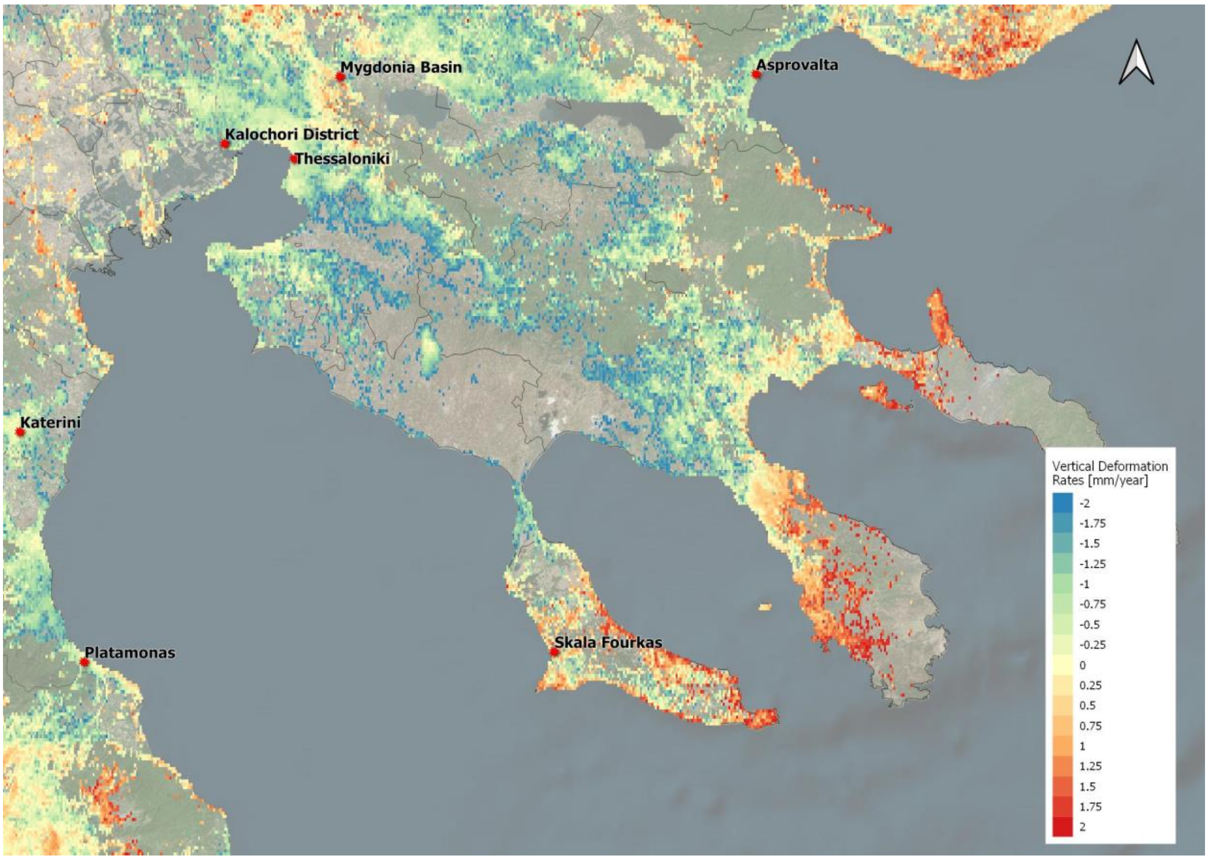

Figure 4 : The mean deformation rates [mm/year] as were estimated using the large SLC SAR acquisitions

4. RESULTS

The derived velocites ranged from -2 mm/year to +2 mm/year along the coastline of the Region of Central Macedonia. High negative values (from -0.75 to -1.75 mm/year), that indicate subsidence, are detected close to Kalochori district and Anthemountas Basin, as espected, as well as close to village of Asprovalta (Fig. 4). Subsidence rates below -0.5 mm/year are also observed on the eastern-southern part of the coastline, close to Platamonas village and the city of Katerini. Along the coastline of Halkidiki (southern peninsulas of the region), the deformation rates imply an uplift trend that has not been reported in previous studies, therefore, taking into account the low accuracy of the method, these results were not evaluated.

In order to estimate the accuracy of the mean deformation rates, a comparison to the results of a coastal engineering study was made. During this study, which took place on behalf of the Managing Authority of Central Macedonia, in situ data from GNSS receivers and sand samplings were combined with high resolution digital elevation and bathymetric models, derived from remote sensing data and UAV photogrammetric data, for the estimation of a 50- and 100-year simulation of the vulnerability of the coastal area, under the pressure of tidal waves (Tsakoumis et al., 2019). The vulnerability of a coastal area is indissolubly linked to erosion phenomena. The derived velocities and the simulation results and juxtaposed in Figures 5a and 5b.

The majority of the SAR velocities that indicate subsidence are observed in areas that should be considered as vulnerable. More specifically, according to the coast engineering study, the most vulnerable areas within a 50 and 100 years period and under high pressure of tidal waves are close to Platamonas, Katerini and Asprovalta villages. Close to Anthemountas basin, the risk does not seem to be high, whereas close to Kalochori district there were no data due to the peculiar topography of the area.

In those specific areas a subsidence trend is also observed from the InSAR analysis. In Platamonas beach, where the risk of erosion from the 50-year simulation is high (Figure 6a, red dots), the derived velocity values range from -0.74 to -2 mm/year, while at the areas where the simulated risk is mediocre, the deformation rates are close to 0. Across the coastline close of Katerini, there is only one “hot” spot, according to the simulation study. At the same spot the InSAR deformation rate is about -1.5 mm/year. Higher surface velocities are observed at the northern part of the coastline (-1.75 to -2 mm/year) as shown in Figure 6b. On the contrary, according to the coast engineers those areas are not identified to be subject to erosion phenomena in the future. Significant deformation rates, that indicate extended subsidence, were calculated at the Anthemountas basin (Figure 6c). In situ data for the erosion study were not collected at the same spots, but in the southern area of the basin, close to the town of Peraia. According to the analysis, the vulnerability risk there is quite high. The InSAR analysis shows a smallert subsidence rate of about -0.75 mm/year. Finally, there is positive correlation between the results of the two studies on Asprovalta beach, as pictured in Figure 6d. Across the coastline the derived velocities range between -0.75 to -2 mm/year, implying serious deformation rates. The risk for erosion that was calculated through the 50-year simulation is medium (yellow dots) across the whole area.

1. CONCLUTIONS

In this work, A correlation between the InSAR derived velocities and the 50 and 100 – year simulation of the coast vulnuarability to erosion is studied. Corelation is high in coastal areas where negative deformation rates were computed and the vulnerabity to erosion was high.

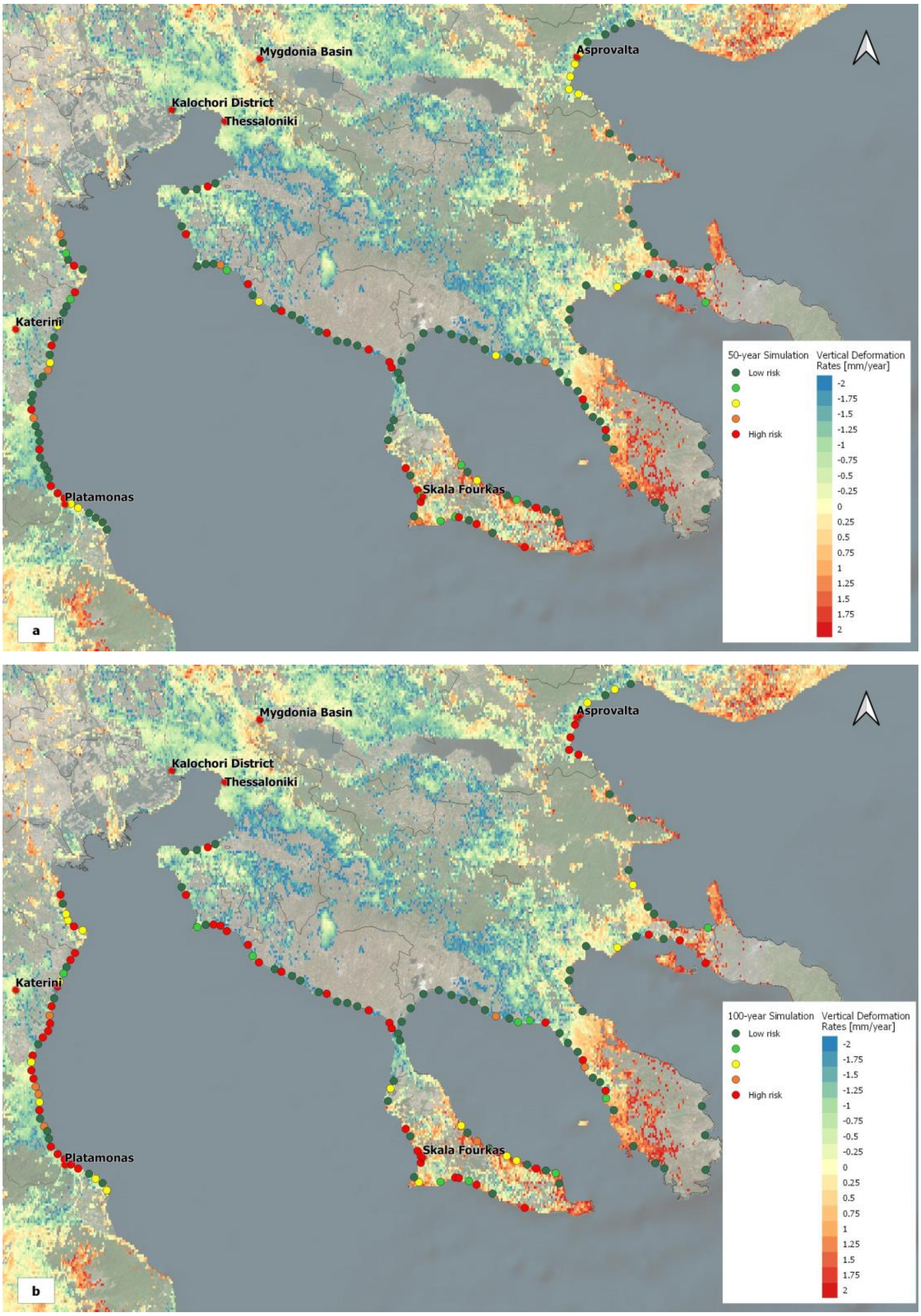

Figure 5 : The results of the 50 –year (a) and 100-year (b) simulation in comparison to the derived SAR velocities

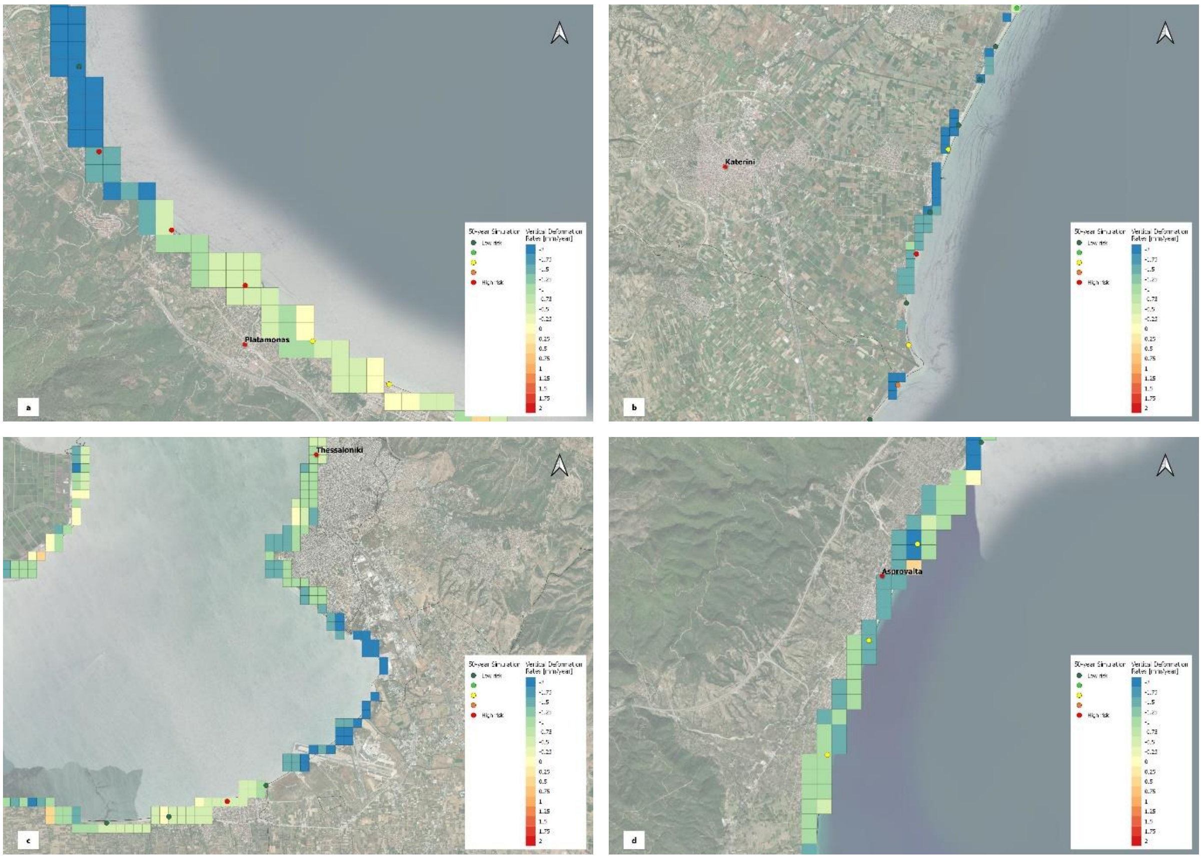

Figure 6. The erosion risk in comparison to the deformation rates on the coastline of Platamonas (a),Katerini (b), Anthemountas Basin (c) and Asprovalta (d)

This should be considered as a positive fact, since it indicates that deformation velocities could be considered as a useful tool for monitoring changes across the coastline that are related to erosion and subsidence phenomena.

Our results imply that using a long time series of SAR images can lead to derive information regarding the temporal evolution of the coastline, over large areas, even though they lack the temporal and spatial resolution provided by traditional methods. Given the fact that InSAR is an inexpensive and easy technique, it outbalances the latter for long-range monitoring and planning.

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